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Assessment of Radon-222 Concentration in Some Selected Borehole and Well Water Sources in Boki Local Government Area, Cross River State, Nigeria

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Abstract: Radon originates from the radioactive decay of naturally occurring uranium and radium deposits found in trace amounts in soil and rocks. The geology of Boki Local Government Area revealed that the area is surrounded with rocks, hills and it is also enriched in clay soil, there is high tendency of radon-222 contamination in the drinking water in the area because clay soil tends to have higher radium concentration and lower porosity, which can lead to greater radon accumulation, which in turn leaches into the drinking water of the inhabitants. This study aims to assess radon-222 concentration in some selected borehole and well water sources in the Boki local government area, Cross River state. Twenty (20) water samples were collected from twenty (20) communities in the study area. The samples were analysed using a liquid scintillation counter as a radon-222 detector. The results showed that the mean radon-222 concentration in the study area is 3.81 Bq/L. The mean Annual Effective Dose (AED) for both inhalation and ingestion was calculated and found to be 0.000094 mSv/yr and 0.9308 mSv/yr, respectively. The Excess lifetime cancer risk (ELCR) for inhalation and ingestion was calculated, and the results are 0.000364 mSv/yr and 3.258 mSv/yr, respectively. The results for the activity of radon-222 concentration, AED, and ELCR are found to be within the recommended dose limit of 10 Bq/L, 0.1 mSv/yr, and 3 mSv/yr, respectively. The drinking water in the study area is safe because it is below the WHO-recommended limit. However, the accumulation of radon-222 over time can exceed the recommended dose limits. The result recommended that proper radon concentration monitoring should be conducted from time to time on the study areas in order to protect the inhabitants.

Keywords: Radon-222, water sources, hazard indices and liquid scintillation detector.

1 Introduction

Water is an essential resource for human survival, and the value of fresh drinking water cannot be overemphasized, with a substantial portion of the world's population relying on groundwater sources, such as wells and boreholes, for their very existence [1- 4]. Water is the major constituent of the Earth's streams, lakes, oceans, and the fluid of most living organisms. It covers about 71% of the Earth's surface. It is vital for all known forms of life, especially humans [5, 6]. Humans use water for various reasons such as transportation, power generation, agriculture, and other domestic activities. Hence, its availability and quality with regard to radiological, microbiological, chemical, and any other form of contamination is a delicate and vital issue [3, 7- 10].

Groundwater contains dissolved Radon from the uranium series, which is present in soil and rocks[11, 12]. Because water is valuable, humans will go to any extent to collect it from several sources, including rivers, streams, rain, wells, and boreholes [13- 16]. Man uses water for various reasons, such as transportation, power generation, Agriculture, and other domestic activities; hence, its availability and quality with regard to radiological, microbiological, chemical, and any other form of contamination are delicate and vital issues [2, 17- 20]. Water, one of the three most important natural resources alongside air and soil, is an essential commodity of life that human beings cannot do without. Hence, its necessity cannot be taken for granted. It serves as a solvent that promotes chemical activities, a

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transportation medium for nutrients, hormones, enzymes, minerals, nitrogenous waste, respiration gases, and several other important functions [21]. To be potable for use without causing damage to human health, water meant for domestic purposes must be free of harmful concentrations of chemicals, pathogenic microorganisms, and radionuclides [22, 23]. Of concern is the presence of radionuclides in water arising from trace amounts of terrestrial radionuclides from the decay series of uranium-238 (^{238}U), thorium-232 (^{232}Th), and the singly occurring potassium-40 (^{40}K), most of which are dissolved solids from rocks, soils, and mineral deposits. The presence of radionuclides in water can cause internal exposure in humans, which results from the decay of radionuclides taken into the body through ingestion and inhalation [24-26]. These radionuclides are then distributed within the sensitive organs of the human body according to the metabolism of the element involved. Radiological concern to human health is the exposure to Radon-222 (^{222}Rn), a noble gas formed from Radium-226 (^{226}Ra), a decay product of ^{238}U. Radon, which has a half-life of 3.8 days, emanates from rocks and soils, tends to concentrate in enclosed spaces like underground mines or buildings. It is a major contributor to the ionizing radiation dose received by the general population [27- 29].

Radon originates from the radioactive decay of naturally occurring uranium and radium deposits found in trace amounts in soil and rocks. Radon decays through the emission of energetic alpha particles; thus, it was classified as a human carcinogen. Radon gas can escape from soil, rocks, and dissolve into groundwater, which can carry it away from its point of origin. ^{222}Rn is a member of the ^{238}U series as a decay product of ^{226}Ra and is in a gaseous state. Radon (^{222}Rn) is an odorless, colorless, and tasteless naturally occurring radioactive inert gas that is soluble in water, having a half-life of 3.82 days [31- 34]. It is a member of the Uranium decay series that contributes the largest proportion of the total radiation from natural sources [30]. There are three naturally occurring isotopes of radon: Radon-222, Radon-219, and Radon-220. Radon-222, which is a decay product of U-238, and a half-life of 3.824 days and emits an alpha particle. It is also soluble in water and organic solvents, the only gas that has radioactive isotopes under normal conditions, occurs naturally, and its density is 7.5 times higher than that of air and is responsible for a large percentage of natural radiation exposure [35- 38].

2 Materials and Method

2.1 Materials

Boki is a local government area of Cross River state in the south-south part of Nigeria. The town is considered to have some of the rugged terrain in Nigeria, for it is almost completely covered by the Cross River rainforest. The town is covered by the Afi mountain. The major communities of the Boki town are Bansan-Osokom, Nsadop Abo, Okundi, Iman, Bateriko, Bumaji, Orimekpang, Wula, Buardr, Natamarte, Kakwagom, Biajua, Kayang, Bashua, Irruan, Boje, Iso-Bendeghe, Abo-Emeh, Borum, and Buanchor. The main activities of the people of Boki town are farming and fishing. Boki is located at 6°16’26N 9°00’36’E (Bonchuk, 2013). A detailed map showing the Local Government Areas of Cross River State and highlighting the Boki Local Government Area, as shown in Figure 1.

2.2 Method of Sample Collection

A composite sampling technique was adopted, which is a technique that requires the collection of different (Borehole and Well) samples at a particular region and merging them together to form a composite sample. Five (5) different well water samples from each community were collected and merged to form a composite sample for each community. This process was also repeated for the borehole water samples. This ensures that all parts of the population are represented in the sample in order to increase the efficiency (that is, to decrease the error in the estimation). A total of twenty (20) water samples (10 Borehole and 10 wells) were collected in twenty (20) communities across the Boki local government area of Cross River state. The samples were collected in clean 1-liter plastic containers with tight covers. The plastic bottles were first washed, cleaned, and rinsed with distilled water to avoid radon present in the samples from being contaminated or absorbed. The water samples were collected after the water was allowed to run for a few minutes. The samples were taken to the laboratory immediately after collection without allowing them to stay long (three days maximum) for analysis. This was done to achieve maximum accuracy and not to allow the composition of the samples to change.

2.3 Method of Sample Preparation

10 ml each of the water samples was transferred into a 20 ml glass scintillation vial to which 10 ml of Insta-Gel scintillation cocktail was added. Having been sealed tightly, the vials were shaken for more than two minutes to extract radon-222 in the water phase into the organic scintillate, and the sample so collected was counted for 60 minutes in a liquid scintillation counter using energy discrimination for alpha particles.

2.4 Method of Sample Analysis

The prepared samples were analysed using a Liquid Scintillation Counter (Tri-Carb LSA 1000TR) model located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The counting was carried out immediately after the prepared samples were brought to the laboratory. The counting vial was placed in the liquid scintillation counter (LSC), and each vial was counted for 60 minutes. It was ensured that the vials were not shaken to avoid disturbing the state of equilibrium between ^{222}Rn and its short-lived daughters in the organic scintillate. The time and date of counting were noted.

2.5 Method of Data Analysis

The results obtained from the sample analyses were used to calculate the radiological hazards associated with Radon-222 in the study area.

2.5.1 Method of Measurement of External Hazard Index

The external hazard index (Hex) was calculated to limit the activity concentration of Radon-222 to ensure that a permissible dose rate of less than 1 mSv/y, as recommended by the World Health Organization (2015), is not exceeded.

$$Hex = \frac{ARa}{370} < 1 \quad (1)$$

Where;
Hex is the external hazard index
ARa is the activity of radon concentration.

2.5.2 Method of Calculating Hazard Parameters for Radon-222 Concentration

The calculations of hazard parameters for Radon-222 concentration consist of the calculation of radon concentration in Bq/L, Annual effective dose by inhalation, annual effective dose by ingestion, and excess lifetime cancer risks in mSv/Yr. The ^{222}Rn concentration was calculated using equation (1) according to [29].

$$R_n\left(Bql^{-1}\right) = \frac{100\ mL\ (C_S - C_B}{10\ mL\ x\ 1.0\ L\ (CF\ x\ D)} \quad (2)$$

Where:
Rn is the Concentration of Radon,
C_S is the Sample count,
C_B is the Background count,
CF is the Calibration Factor
D is the Decay correction factor.

2.5.3 Method of Determining Annual Effective Dose from Radon-222

The annual effective dose was calculated using equation (3.2) according to [28].

$$E = Rn \times D \times L \quad (3)$$

Where;

E is the Annual effective dose by ingestion (mSv/yr),
Rn is the Concentration of Radon,
D is the Dose coefficient (105 mSv/yr)
L is the Annual water consumption, 2L/d (730 L/yr).

2.5.4 Method of Calculating Annual Effective Dose Due to the Ingestion of Radon-222

Annual effective dose due to the ingestion of radon from the underground E(ing) was calculated using Equation (3).

$$Eing = C_{Rn}\ (Bql^{-1}) \times Ding \times Dw \times F \times T \quad (4)$$

Where:
CRn is the mean radon (^{222}Rn) activity concentration in water,
Dw is the daily water ingestion (2L day^{-1}),
Ding is the ingesting dose conversion factor of radon (10−8 Sv Bq^{-1}), T is equal to 365-day y^{-1}

2.5.5 Method of Calculating Excess Lifetime Cancer Risk (ELCR)

This is associated with the probability of developing cancer over a lifetime at a given exposure level. It is a value depicting the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose. An increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate, or even blood. Excess lifetime cancer risk (ELCR) for Ingestion was calculated using equation (3.4).

$$ELCR = AED_{(ing)} \times D_L \times R_F \quad (5)$$

Where: ED is the Effective Dose, D_L is the average duration of life/life expectancy (estimated as 70years), R_F is the Risk Factor (Sv^{-1}), i.e., fatal cancer risk per Sievert. For stochastic effects, the International Commission on Radiological Protection (ICRP) uses RF as 0.05 Sv-1 for the public [34].

3 Results and Discussion

The study assesses Radon-222 concentration in some selected borehole and well water sources in Boki local government area, Cross-River state, Nigeria. Twenty (20) samples of water from boreholes and wells were collected and analyzed for radon-222 concentration using a liquid scintillation detector.

Table 1 presents the radon-222 concentration in the boreholes and well water sources in the study area. The data for radon-222 concentration in the drinking water of the study area show significant differences. The mean of the activity radon-222 concentration is 3.81 Bq/L. The activity radon concentration differs, as shown in the table. The highest activity of radon-222 concentration is 7.38 Bq/L found at the BIA community. The least active radon-222 concentration is 2.36 Bq/L found at the KAY community. The results indicated that there is radon-222 contamination in the study area. This could be dangerous to the health of the inhabitants over time.

Table 1: Radon-222 (^{222}Rn) Concentration of Samples in Bq/L.

SN	Sample ID	Source	Location	Sample Count (CPM)	Radon-222 Concentration (Bq/L)
1.	BAS	Borehole	Bashua	77.70	4.48
2.	BIA	Borehole	Biajua	101.70	7.38
3.	BET	Borehole	Beteriko	81.57	4.94
4.	BUA	Borehole	Buanchor	95.65	6.60
5.	IRR	Borehole	Irruan	62.55	4.60
6.	NSA	Borehole	Nsadop Abo	81.88	4.98
7.	NTA	Borehole	Ntamante	64.40	2.87
8.	OKU	Borehole	Okundi	64.50	2.88
9.	ORI	Borehole	Orimekpang	67.87	3.29
10.	WUL	Borehole	Wula	71.27	3.70
11.	ABO	Well	Abo-Eme	66.12	3.08
12.	BAN	Well	Bansan-Osokom	70.33	3.59
13.	BOJ	Well	Boje	66.68	3.15
14.	BOR	Well	Borum	59.38	2.26
15.	BUA	Well	Buardwr	60.85	2.44
16.	BUM	Well	Bumaji	64.37	2.87
17.	IMA	Well	Iman	77.40	4.44
18.	ISO	Well	Iso-Bendeghe	69.98	3.54
19.	KAK	Well	Kakwagwom	63.62	2.78
20.	KAY	Well	Kayang	60.15	2.36
	Mean			**71.40**	**3.81**

When comparing the mean result of the present study to the other studies from the literature, the mean of these results is supported by the findings of Rilwan *et al*. (2023), which calculated the mean of the activity radon concentration of 3.91 Bq/L, and Rani *et al.* (2021), which calculated the mean of the activity Radon-222 concentration to be 3.37 Bq/L. The results disagreed with the findings of Tabar and Yakut (2020), who calculated the mean of the activity concentration of radon-222 to be 2.40, and Khaleel *et al.* (2019), who calculated the mean of the activity concentration of radon-222 to be 11.8 Bq/L.

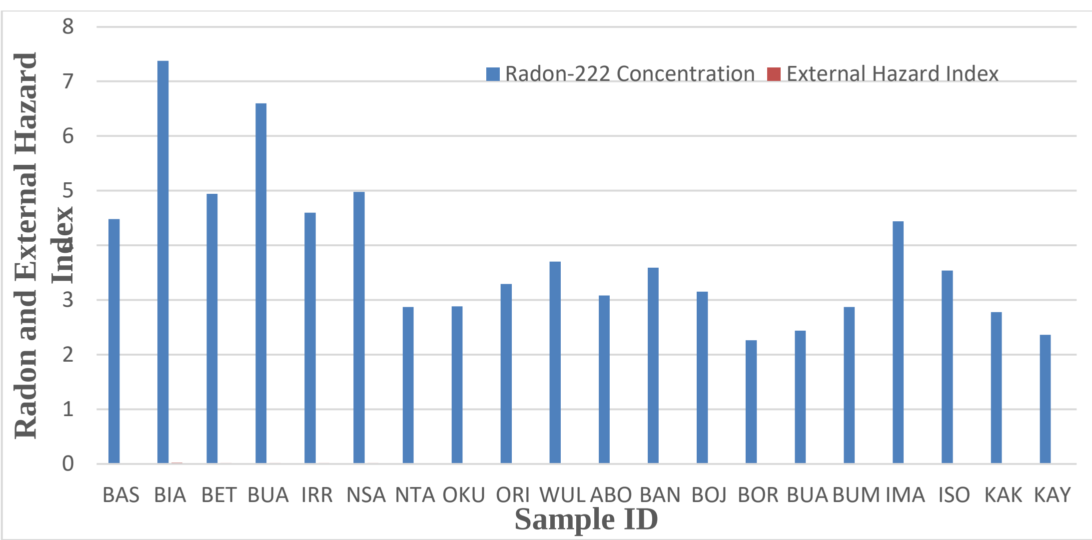

Fig. 2: Radon-222 concentration and external hazard index.

Figure 2 presents the result of radon-222 concentration in Bq/L and external hazard index in mSv/y. The radon-222 concentration has an average of 3.81 Bq/L, and the external hazard index has an average of 0.0104 mSv/yr. The radon-222 concentration is below the recommended limit of 11.0 Bq/L as recommended by WHO (2015). The external hazard index is less than 1 mSv/yr, which is the minimum recommended limit as recommended by WHO (2015). The findings are supported by the findings of Rilwan *et al*. (2023), which calculated the mean of the activity radon concentration of 3.91 Bq/L. The results also agreed with the findings of Rani et al. (2021), who calculated the mean of the activity Radon-222 concentration to be 3.37 Bq/L. The results disagreed with the findings of Tabar & Yakut (2020), who calculated the mean of the activity concentration of radon-222 to be 2.40.

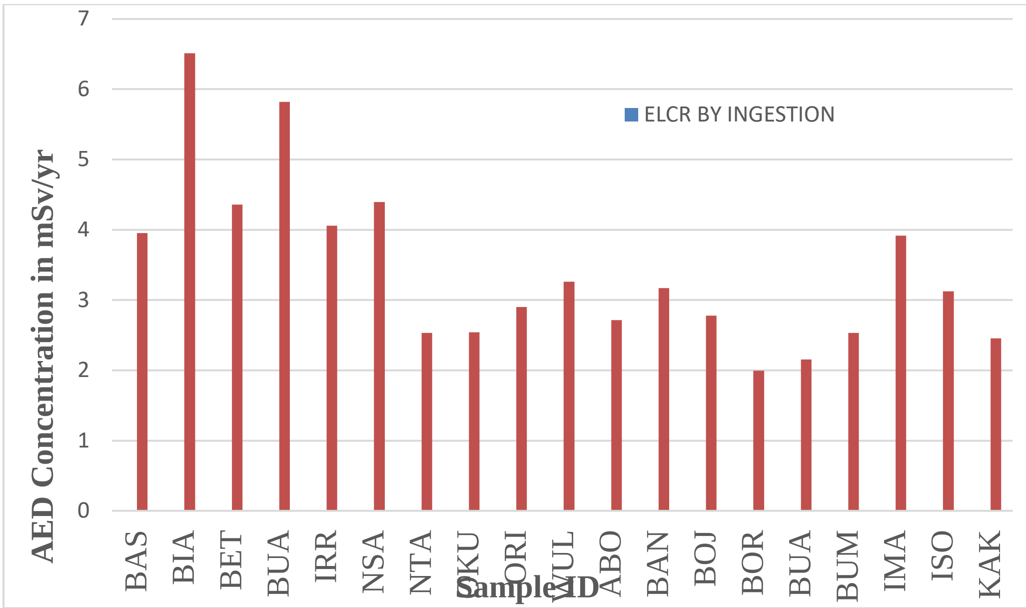

Fig. 3: Annual Effective Dose by Inhalation and Ingestion.

Figure 3 presents the annual effective dose by ingestion of radon-222 in 20 different water samples from borehole and well water for BAS, BIA, BET, BUA, IRR, NSA, NTA, OKU, ORI, WUL, ABO, BAN, BOJ, BOR, BUA, BUM, IMA, ISO, KAK, and KAY. The mean of the annual effective dose by ingestion is recorded as (0.000094) mSv/yr. The annual effective dose by ingestion (AEDEing) varies, as the highest value of 0.00023 mSv/Yr is recorded at the BIA community. The least AEDEing is 0.00006 mSv/Yr is recorded at the KAY community. The table also presents the annual effective dose by inhalation of radon-222 in 20 different water samples from borehole and well water for BAS, BIA, BET, BUA, IRR, NSA, NTA, OKU, ORI, WUL, ABO, BAN, BOJ, BOR, BUA, BUM, IMA, ISO, KAK, and KAY. The mean of the annual effective dose by inhalation (AEDEinh) is recorded as 0.9286 mSv/yr. The results of the AEDEinh vary in the communities, as the highest value of 1.860 mSv/Yr is recorded at the BIA community. The least value of 0.570 mSv/Yr is recorded at the KAY community. When comparing the mean result of AED by inhalation and ingestion of the present study to the other studies from the literature, the mean of these results is supported by the findings of Rilwan *et al*. (2023), who calculated the mean of the AED inhalation and ingestion of 0.000051 and 0.985 mSv/Yr, respectively. The results disagreed with the findings of Rani et al. (2021), which calculated the mean AED to be 0.17 and 0.59 mSv/Yr, respectively. The results disagreed with the findings of Tabar and Yakut (2020), who calculated the mean AED for inhalation and ingestion to be 0.2 and 2.44 mSv/Yr, respectively. In addition, the results had a disagreement with the results of Khaleel et al. (2019), which calculated the mean AED to be 0.05 mSv/yr and 1.43 mSv/Yr, respectively. The AED inhalation and Ingestion results for the present study are within the recommended AED doses of 0.1 and 2.4 mSv/yr as recommended by WHO (2015). These findings indicate that the annual effective dose (AED) for both inhalation and ingestion is within the recommended dose limit. However, the accumulation of radon-222 can cause detrimental health implications.

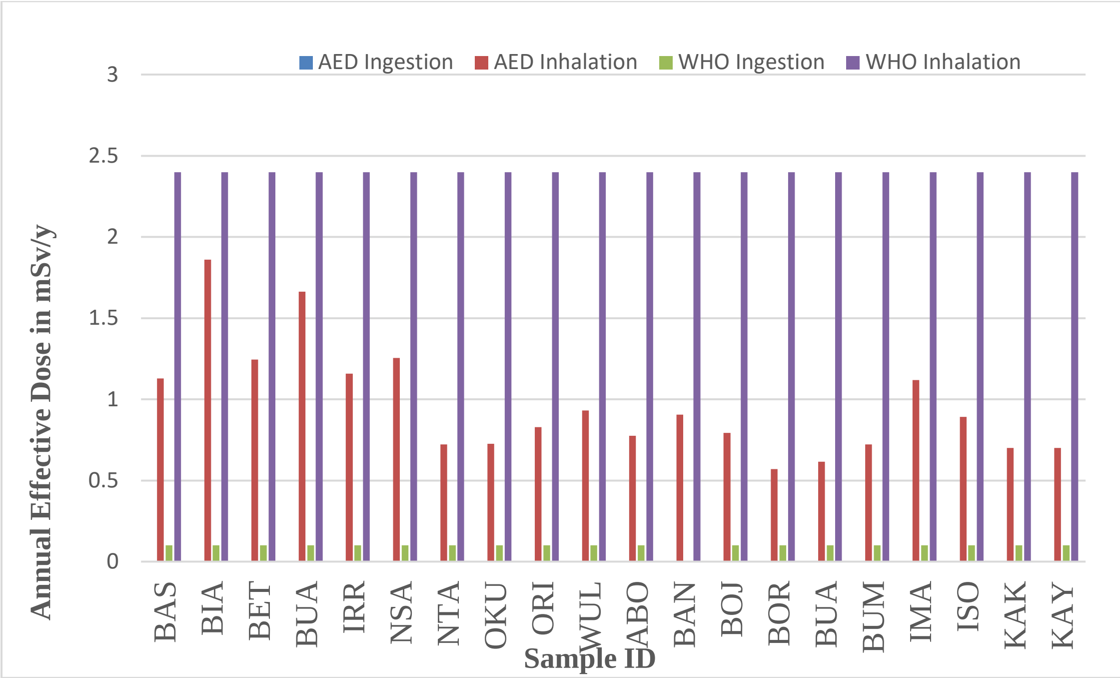

Fig.4: Comparison of the Annual Effective Dose with WHO, 2015.

Figure 4 presents the comparison between the Annual effective dose by ingestion and inhalation in this study and that of the World Health Organization. The comparison shows that the AED by ingestion and inhalation is below the recommended limit. The findings show that the water sources of the study area are safe for domestic purposes. However, the accumulation of radon-222 over a period of time can cause harm to health. Therefore, it is recommended that precautionary measures be taken when using the water.

Figure 5. present the excess lifetime cancer risk by ingestion of radon-222 in twenty (20) different water samples from borehole and well water for BAS, BIA, BET, BUA, IRR, NSA, NTA, OKU, ORI, WUL, ABO, BAN, BOJ, BOR, BUA, BUM, IMA, ISO, KAK, and KAY. The mean of the annual effective dose by ingestion is recorded as 0.000364 mSv/Yr. The highest value of excess lifetime cancer risk by ingestion of radon-222 is 0.00081 mSv/Yr recorded at the BIA community. The least ECLRing is 0.00025 mSv/Yr recorded at the KAY community. The table and chart also present the excess lifetime cancer risk by inhalation with a mean of 3.258 mSv/Yr. The highest value of ELCRinh of radon-222 is 6.510 mSv/Yr recorded at the BIA community.

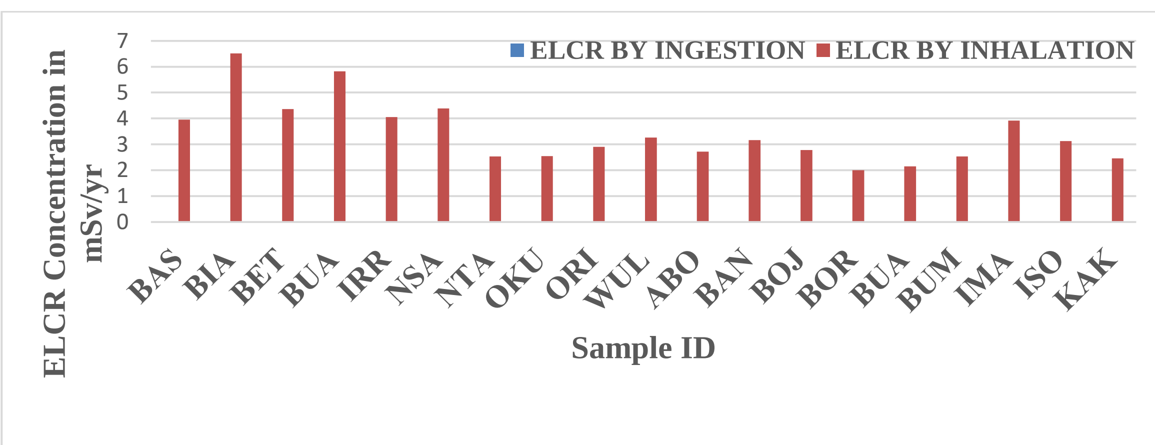

Fig. 5: Excess Lifetime Cancer Risk by Ingestion and Inhalation.

Table 6: Comparison of the current study with studies from other Countries.

SN	Citation	Country	Findings
1.	Present Study	Nigeria	3.81 Bq/L
2.	Rilwan *et al*. (2023)	Nigeria	3.91 Bq/L
3.	Almoniem & Elzain, 2014	Sudan	6.93 Bq/L
4.	Samer *et al*. (2016)	Lebanon	11.4 Bq/L
5.	Xinwei *et al*. (2016)	China	12.00 Bq/L
6.	Khaleel *et al*. (2019)	Egypt	11.8 Bq/L
7.	Tabar and Yakut (2020)	Turkey	2.4 Bq/L
8.	Rami *et al*. (2021)	India	3.37 Bq/L
9.	Abdulmalik *et al*. (2021)	Malaysia	3.11 Bq/L

The least ECLRinh is 1.995 mSv/Yr recorded at KAY community. When comparing the mean result of ELCR by inhalation and ingestion of the present study to the other studies from the literature, the mean of these results is supported by the findings of Rilwan *et al*. [5], who calculated the mean of the ELCR inhalation and ingestion of 0.00018 and 3.45 mSv/Yr, respectively. The results disagreed with the findings of Rani *et al*. [3], which calculated the mean ELCR to be 0.17 and 0.59 mSv/Yr, respectively. The results disagreed with the findings of Tabar and Yakut (2020), who calculated the mean ELCR for inhalation and ingestion to be 0.2 and 2.44 mSv/Yr, respectively. In addition, the results had a disagreement with the results of Khaled *et al*. [19], which calculated the mean ELCR to be 0.05 mSv/yr and 1.43 mSv/Yr, respectively. The ELCR inhalation and Ingestion results for the present study are within the recommended ELCR doses of 0.29 and 3.45 mSv/yr as recommended by WHO [4].

4 Conclusion

The study assessed the Radon-222 concentration in borehole and well water sources in twenty (20) communities in the Boki local government. The findings of the study indicated that there is the presence of Radon-222 in the water samples collected. However, the level of radon-222 is below the recommended radon limit. The annual effective dose and excess lifetime cancer risks were assessed and found within the safety limit as recommended by the World Health Organization (WHO).

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